DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

JUL 24 2001

FROM: HQ AFCESA/CESC
139 Barnes Drive, Suite 1
Tyndall AFB FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 01-10: Design and Construction of High-Capacity Trim Pad Anchoring Systems**

1. Purpose. This ETL presents a design for an aircraft trim pad anchoring system capable of supporting a working load of 100 kilopounds (kip) (444.8 kilonewtons [100,000 pounds]) of thrust. While the guidance within this ETL is not mandatory, this design has been verified to withstand the greater thrust loads projected for the next generation of fighter aircraft.

2. Application: All Air Force installations supporting flight operations.

2.1. Authority: AFMAN(I) 32-1123, *Airfield and Heliport Planning and Design* (Unified Facilities Criteria [UFC] Index Number 3-260-01).

2.2. Effective Date: Immediately.

2.3. Ultimate Recipients:

- Base civil engineers (BCE), Rapid Engineers Deployable – Heavy Operations Repair Squadron Engineers (RED HORSE) squadrons, and other Air Force units responsible for design, construction, maintenance, and repair of trim pads.
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction.

2.4. Coordination: Major command (MAJCOM) pavement engineers

3. Referenced Publications:

- AFRL/MLQC Technical Report, *High Capacity Aircraft Anchor Block Design and Analysis,* December 1998
- AFMAN(I) 32-1123, *Airfield and Heliport Planning and Design* (UFC 3-260-01)
- ETL 00-2, *Inspection and Testing of Trim Pad Anchoring Systems*

4. Acronyms and Terms:

AFRL/MLQC	- Air Force Research Laboratory/Material Directorate/Air Base Environmental Division/Air Base Technology
BCE	- base civil engineer
BHN	- Brinell hardness
ETL	- Engineering Technical Letter

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HQ ACC/CE	- Headquarters Air Combat Command/Civil Engineer
in	- inch
kip	- 1000-pound load (kilopound)
ksi	- kips per square inch
MAJCOM	- major command
mm	- millimeter
MPa	- megapascal
O.C.	- on center
psi	- pounds per square inch
RED HORSE	- Rapid Engineers Deployable – Heavy Operations Repair Squadron Engineers
R.T.	- room temperature
USACE	- U.S. Army Corps of Engineers

Aircraft anchor: A thrust-resisting structure constructed by embedding a steel anchor block trim pad into a large reinforced concrete block tied to the surrounding anchor concrete slab, and used to constrain fighter aircraft during power checks and routine engine maintenance procedures.

5. Introduction.

5.1. Background. Most Air Force fighter (and some trainer) aircraft use aircraft anchor blocks during power checks and routine engine maintenance procedures. Many existing aircraft anchor blocks were designed to withstand loads associated with F-4 operations; however, the next generation of fighters will employ engines with much greater thrusts than any fighter aircraft currently in inventory. A new generation of aircraft anchor blocks will be required to meet the increased requirements. Consequently, HQ ACC/CE funded AFRL/MLQC to design, analyze, and test a high-capacity anchor block capable of a 444.8-kilonewton (100-kip) working load. This ETL summarizes that project and presents the resulting design.

5.2. Objective. The objective of the project was to update the design of the anchor block to handle loads exceeding 444.8 kilonewtons (100 kips) and verify that such loads can be facilitated with a sufficient factor of safety.

5.3. Scope. The scope of the project consisted of the redesign of the anchor block and full-scale verification, limited to the components of the anchor block. Distinct aspects or tasks within the scope of the effort consisted of the following:

5.3.1. Review of Current Designs and Interaction with Users. Current anchor block designs were reviewed, and past problems, observations, and potential improvements were discussed with users and fabricators.

5.3.2. Design and Analysis. The high-capacity anchor block was designed, and each component of the structure was analyzed for its level of safety, interaction between components, and the likely failure mode of the system if overloaded.

5.3.3. Field Testing. A full-scale anchor block was field-tested and strength of the system verified with an adequate factor of safety.

5.3.4. Report. The results were summarized in AFRL/MLQC Technical Report, *High Capacity Aircraft Anchor Block Design and Analysis*.

5.4. Overview.

5.4.1. The high-capacity anchor block is essentially a redesign (with increased strength) of the standard "bi-directional" anchor system. This geometry was chosen because of (1) its structural efficiency and predictability; (2) a lack of known problems with existing "standard" anchor blocks; (3) a geometry and construction familiar to the users; and (4) relative ease of construction. After preliminary design, each component was assessed for its factor of safety for 444.8 kilonewtons (100 kips) using simplifying (but conservative) assumptions, energy methods, and basic engineering mechanics. Following the component assessments, finite element models of the structure were used to investigate the overall behavior of the system, interaction between components, and stress concentrations.

5.4.2. Two full-scale test blocks were fabricated to experimentally verify the strength of the system and identify any problems with construction and manufacturing of the steel components. After curing the concrete, a pull force simulating aircraft engine thrust was applied. The design load of 444.8 kilonewtons (100 kips) was applied for 5000 cycles and held at 444.8 kilonewtons (100 kips) for 20 minutes. This was increased to 556, 667.2, 778.4, and 889.6 kilonewtons (125, 150, 175, and 200 kips) and held at each for 15 minutes. The test blocks were also severely vibrated at 444.8 and 889.6 kilonewtons (100 and 200 kips) for 10 minutes each. All of the loads were applied at approximately 20 degrees with the horizontal plane. Displacement and strain at points of interest on the curved steel loop were measured and compared to analytical results.

6. Design and Analysis.

6.1. Analysis. As noted in paragraph 5.4, a thorough analysis of individual components, component interaction, stress concentrations, and overall stability was completed during the project. The ultimate goal of the analysis was to predict and understand the failure mode that will likely occur and to predict the ultimate factor of safety of the system. To do this, the entire system was modeled in detail using the finite element method. Points of interest included stress concentration at the interfaces between the steel anchor and concrete block, overturning, and yielding of the steel anchor. These analyses concluded that the assumptions used in the component analyses were conservative and that *the likely mode of failure will be rupture of the* *metal link.* Inspecting stress concentrations at steel/concrete interfaces did not reveal any significant concerns. Table 1 summarizes the minimum factors of safety.

Table 1. Minimum Factors of Safety

Potential Failure Mode	Factor of Safety*
Initial yield of the 76-mm (3-in) diameter bar made of 689.5 MPa (100 ksi) yield alloy	1.7
Initial yield of the 76-mm diameter bar made of Astralloy®	2.5
Rupture of the 76-mm diameter bar made of 689.5 MPa (100 ksi) yield alloy	2.9†
Rupture of the 76-mm diameter bar made of Astralloy®	4.3†
Initial yield of the 63-mm (2.5-in) diameter metal link made of 689.5 MPa (100 ksi) yield alloy	1.0
Initial yield of the 63-mm diameter metal link made of Astralloy®	1.5
Rupture of the 63-mm diameter metal link made of 689.5 MPa (100 ksi) yield alloy (not including the weld)	1.7
Rupture of the 63-mm diameter metal link made of Astralloy® (not including the weld)	2.5
Overturning the concrete block for load applied at 20 degrees	2.3
Crushing the concrete at the bar/block interface	8‡
Crushing the concrete at the block/pad interface	10+
Pullout of the steel anchor	10+

* Estimated <u>minimum</u> factor of safety with respect to the 444.8-kilonewton (100-kip) design load based on engineering analyses.

† Estimated using the shape factor for a solid circular cross-section.

‡ Based on 27.5-megapascal (4000-psi) concrete.

6.2. Fatigue. No fatigue related problems have been noted for other blocks that have been used for years. Fatigue, however, is always an issue for structures subjected to repeated loading; particularly if connections are welded. The critical areas for routine visual inspection should include the surface at the steel-concrete interfaces, the top of the weld between the curved bar and the web plate, and the weld on the metal link. Observable permanent deformation of the steel bar would indicate that appreciable plastic strains have occurred and that the strength of the system should be reviewed more carefully. Because fatigue is a concern and difficult to predict analytically, the anchor blocks were loaded up to the 444.8-kilonewton (100-kip) design load for several thousand cycles.

6.3. Final Design Drawings. Final design drawings prepared by AFRL/MLQC personnel are in Attachment 2.

7. Construction.

7.1. Materials and Manufacturing. The design calls for a high-strength alloy with a yield strength of at least 689.5 megapascals (100 kips per square inch). A high-strength alloy must be used to keep the thickness of the bar to a diameter that can be bent 180 degrees at an inside radius of 101 millimeters (4 inches). Also, a thicker bar would make connection design more difficult.

7.1.1. There are a number of high-strength alloys that could feasibly be used for the steel anchor. Some important characteristics of the metal used should be:

- Yield strength of at least 689.5 megapascals (100 kips per square inch).
- The ability to be curved to the design radius without losing strength.
- Compatibility with concrete.
- Corrosion resistance in an environment with high salt concentration in the air.
- No change in engineering properties up to 537 °C (1000 °F).
- Good fatigue characteristics.

The manufacturer and fabricator of the metal anchor used in the tests conducted by AFRL was Astralloy, Inc. Astralloy® was chosen because of its superior strength characteristics and because of the ability of the manufacturer to construct the test anchors in a short time. Astralloy® has a tensile yield strength of approximately 1103 megapascals (160 kips per square inch) and an ultimate strength up to 1654 megapascals (240 kips per square inch), depending on the quenching and tempering methods used. It is engineered for highly abrasive environments and therefore has superior hardness characteristics. Additional product information for Astralloy® is provided in Table 2.

Table 2. Astralloy® Product Information

Typical 25-mm (1-in) Air-Hardened Astralloy®-V Plate									
Hardness (BHN)	MPa (ksi)		Elongation in 50 mm (2 in)	Reduction in Area	Modulus of Elasticity MPa (psi)	V Notch Toughness (ft/lb)			
	Tensile	Yield				Longitudinal		Transverse	
						R.T.	-73 °C (-100 °F)	R.T.	-73 °C (-100 °F)
444	1661.6 (241.0)	1082.4 (157.0)	11.7%	39%	202,016.4 (29,300,000)	31	20.8	29.3	17.8

Typical Air-Hardened and -Tempered Astralloy®-V Bars					
Size (Diameter)	Hardness (BHN)	Tensile MPa (ksi)	Yield MPa (ksi)	Elongation in 50 mm (2 in)	Reduction in Area
25 mm (1 in)	363	1261 (182.9)	1149.3 (166.7)	13%	55%
127 mm (5 in) surface	356	1205.8 (174.9)	1036.2 (150.3)	14.6%	59%
127 mm (5 in) core	356	1202.4 (174.4)	999 (144.9)	14.3%	56%
203 mm (8 in) surface	363	1220.3 (177.0)	906.6 (131.5)	14%	45%
203 mm (8 in) core	363	1213.4 (176.0)	875.6 (127.0)	10%	42%

7.2. Construction Techniques. Photographs illustrating construction of the high-capacity trim pad anchor at the Tyndall Air Force Base AFRL complex are provided in Attachment 3.

7.2.1. Cutting and Excavating Block Area. A 1.5-meter (5-foot) perimeter was cut to create a 2-square-meter (22-square-foot) area from the existing pad. This was done to ease in building formwork, provide continuity of rebar between the block and the surrounding slab, and ensure that the soil immediately surrounding the blocks was sufficiently compacted.

7.2.2. Formwork. A plywood form was built. After curing the concrete, the top of the form was cut away so there would be no wood between the block and the surrounding pad.

7.2.3. Placement of Steel Anchors. The anchors were hung from beams spanning the width of the block. The steel anchor weighs approximately 226 kilograms (500 pounds), so the beams must be sufficiently strong and stiff. The orientation and elevation of the anchor was checked before pouring the concrete.

7.2.4. Placement of Rebar. The rebar is designed so that pulling out the steel anchor would require pulling out the top layer of rebar. The top layer of rebar is set over the 63-millimeter (2.5-inch) steel dowels that go through the web of the steel anchor. A minimum cover of 203 millimeters (8 inches) should be provided and checked before the concrete is poured.

7.2.5. Pouring and Finishing Concrete. Approximately 15,300 liters (20 yards) of concrete is needed for each block. Concrete must be placed evenly on both sides of the anchor so the anchor will not move while pouring. 34.4-megapascal (5000-psi) concrete was used in the AFRL tests.

8. Field Testing. The new design underwent severe testing, including ultimate load and repetition (see paragraph 5.4). In general, the anchor system behaved as expected and appeared to easily achieve loads up to 889.6 kilonewtons (200 kips); however, the weld of one of the metal links failed at 4500 cycles of 444.8 kilonewtons (100 kips). Based on information from the fabricator, the welds should have a strength easily exceeding 444.8 kilonewtons (100 kips), which would be the approximate tensile load at the weld under a pull of 889.6 kilonewtons (200 kips) (little bending is present at that location). It was concluded that this weld was defective. After fracturing, the link was replaced by a shackle of comparable strength and dimensions and the test continued. The second link completed the test with no indication of problems.

9. Summary. An aircraft anchor system has been designed and its capacity greater than 889.6 kilonewtons (200 kips) verified through full-scale testing. Construction issues were addressed, detailed analyses were conducted, using both closed-form solutions and finite element analyses, and comparison between closed-form solutions, finite element results, and test results revealed excellent correlation. The following general recommendations resulted from the project:

9.1. Adhere to the guidelines for high-strength alloy selection outlined in paragraph 7.1, particularly considering yield strength. Note that 444.8-kilonewton (100-kip-per-square-inch) yield strength material only produces a safety factor of 1.0 (with respect to yield); thus, higher strength alloys such as Astralloy® are recommended.

9.2. When possible, use a commercially available shackle connection that has a certified working load rather than a welded metal link. If a welded metal link must be used, require the manufacturer to carefully inspect and certify the weld for defects.

9.3. Consider a redundant system, such as attaching the aircraft to two anchors (embedded within a single concrete block), each of which is capable of carrying the design load if the other fails.

9.4. Routinely inspect the anchors, particularly for fatigue-related problems.

9.5. Although the testing procedure outlined in ETL 00-2, *Inspection and Testing of Trim Pad Anchoring Systems*, is valid for the design described in this ETL, this new design has far more capacity than current portable test equipment can verify.

10. Points of Contact: Recommendations for improvements to this ETL are encouraged and should be furnished to: HQ AFCESA/CESC, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, Attention: Dr. Randall Brown, HQ AFCESA/CESC, DSN 523-6338, commercial (850) 283-6338, Internet Randall.Brown@tyndall.af.mil, FAX (850) 283-6219; Mr. Brian Cotter, HQ AFCESA/CESC, DSN 523-6083, commercial (850) 283-6083, Internet Brian.Cotter@tyndall.af.mil, FAX (850) 283-6219.

MICHAEL J. COOK, Colonel, USAF
Director of Technical Support

3 Atch
1. Design Drawings
2. Construction Photos
3. Distribution List

DESIGN DRAWINGS

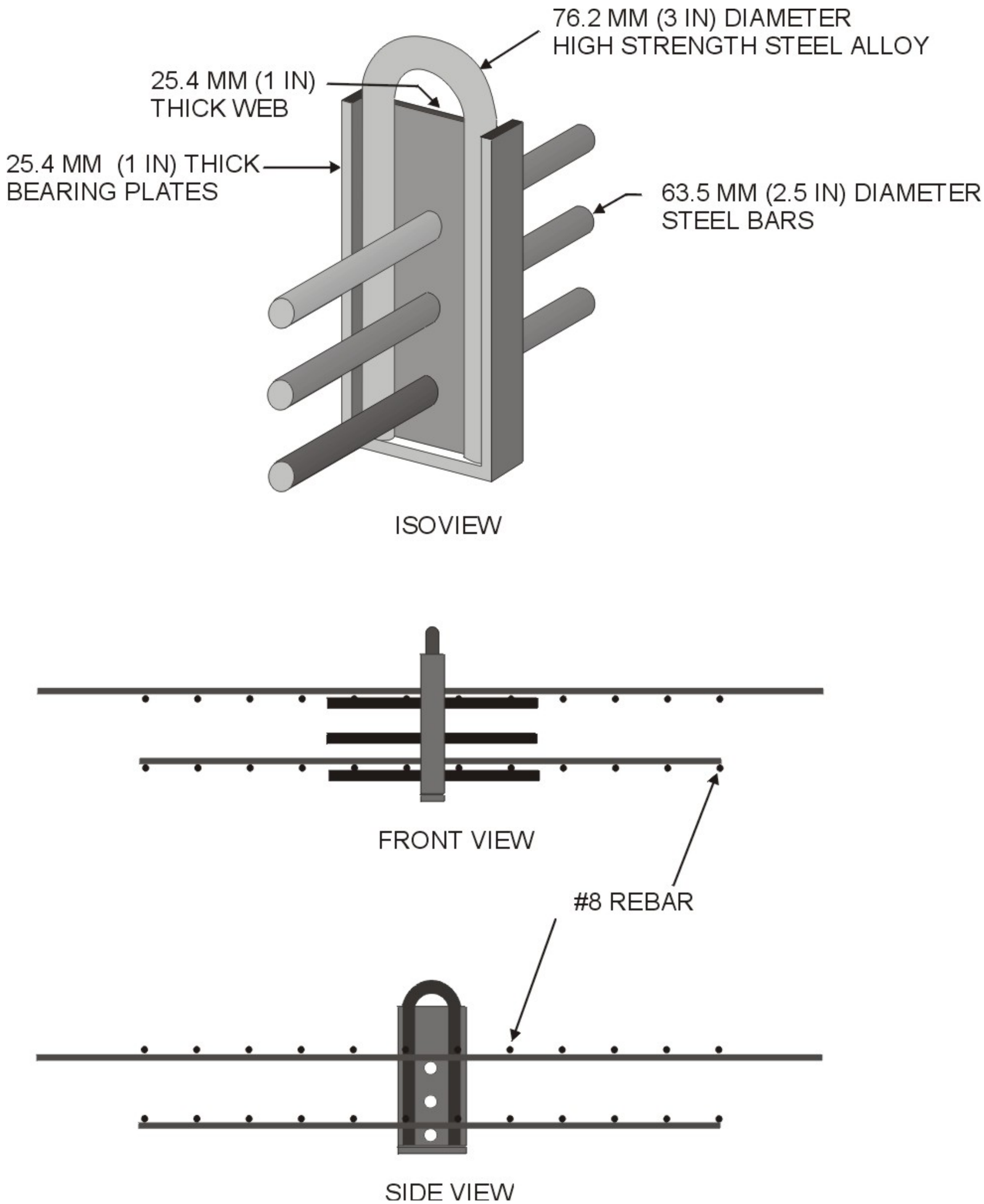

Figure A1. Steel Anchor Description

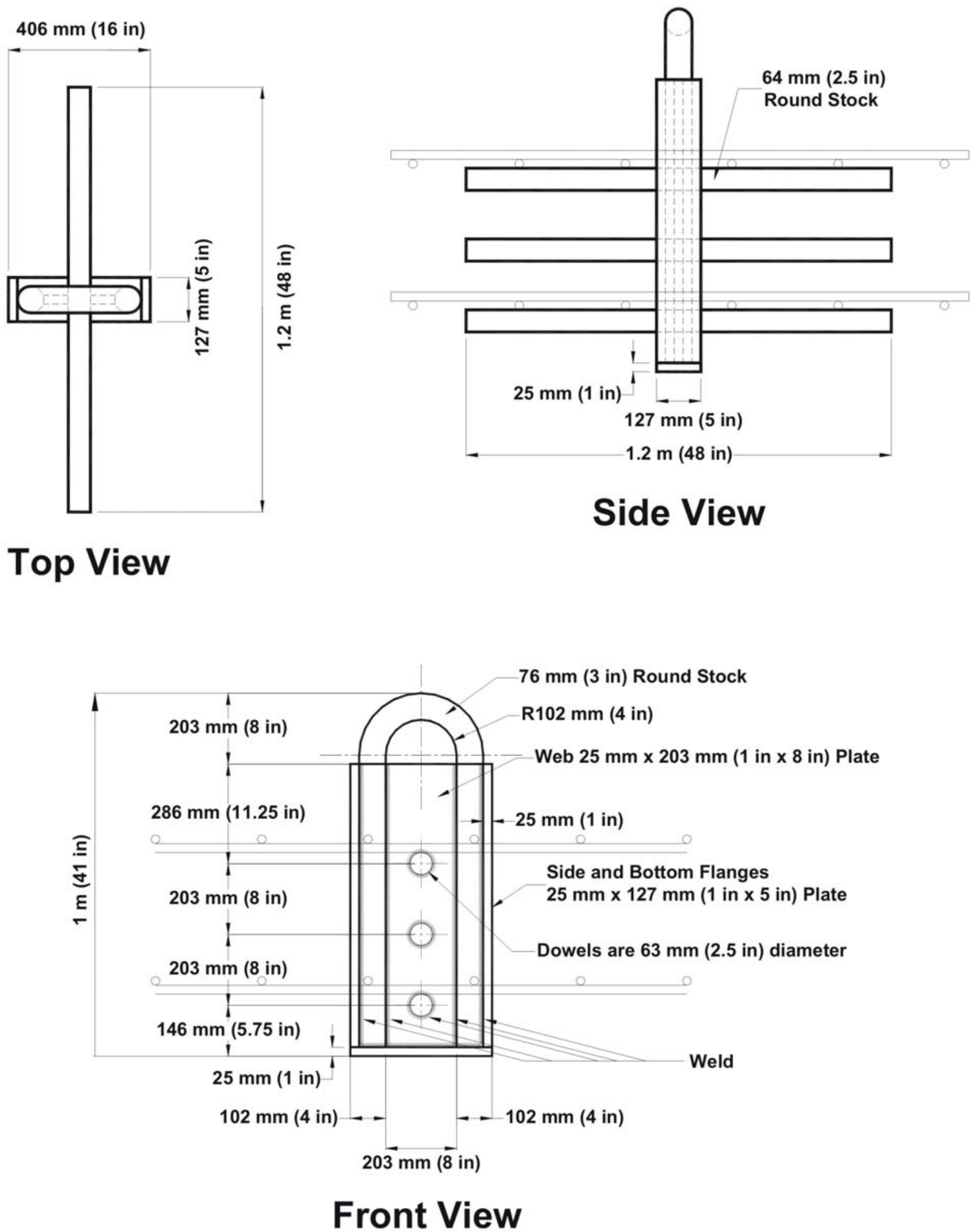

Figure A2. Steel Anchor Dimensions

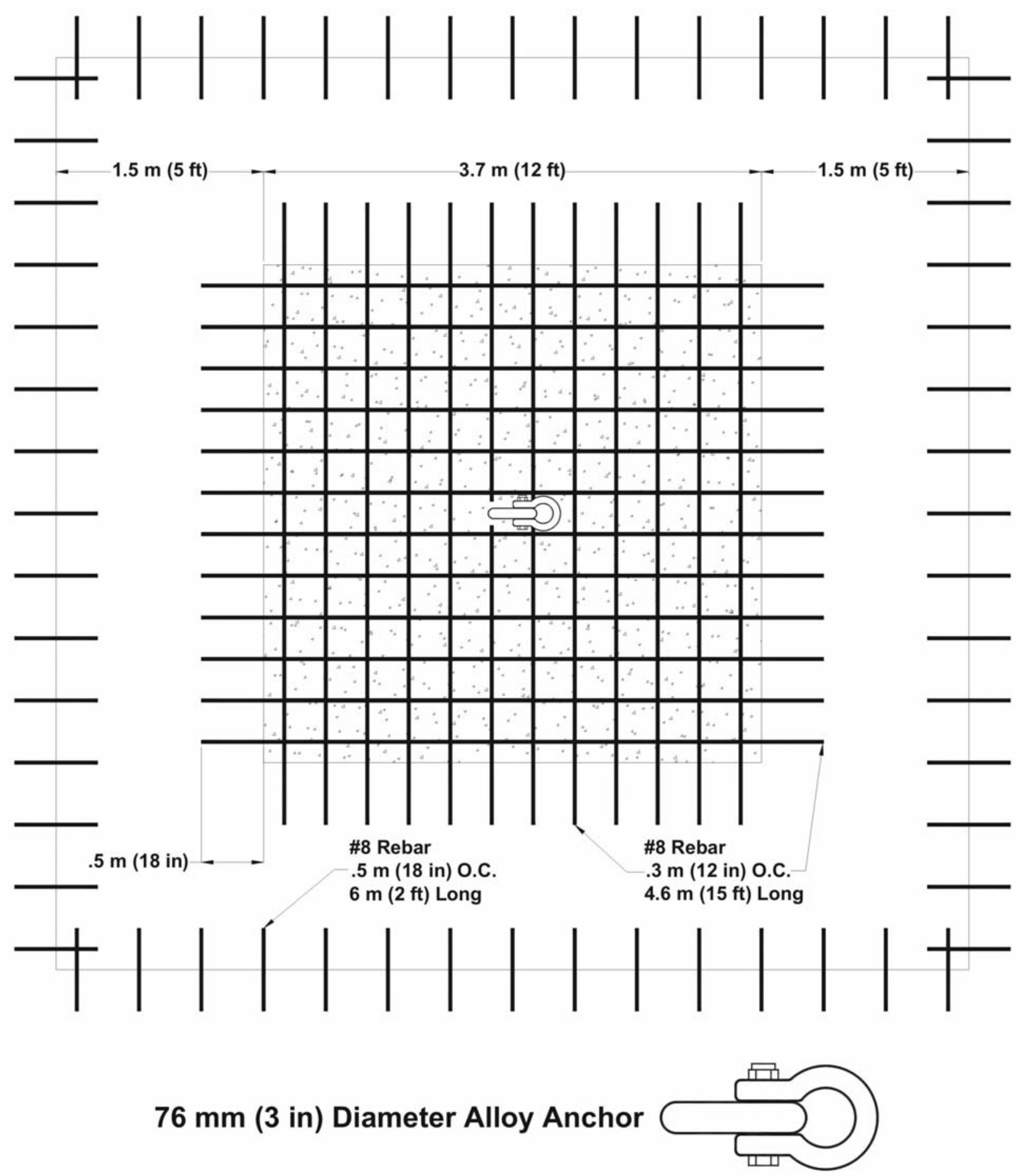

Figure A3. Anchor Block Construction – Plan View

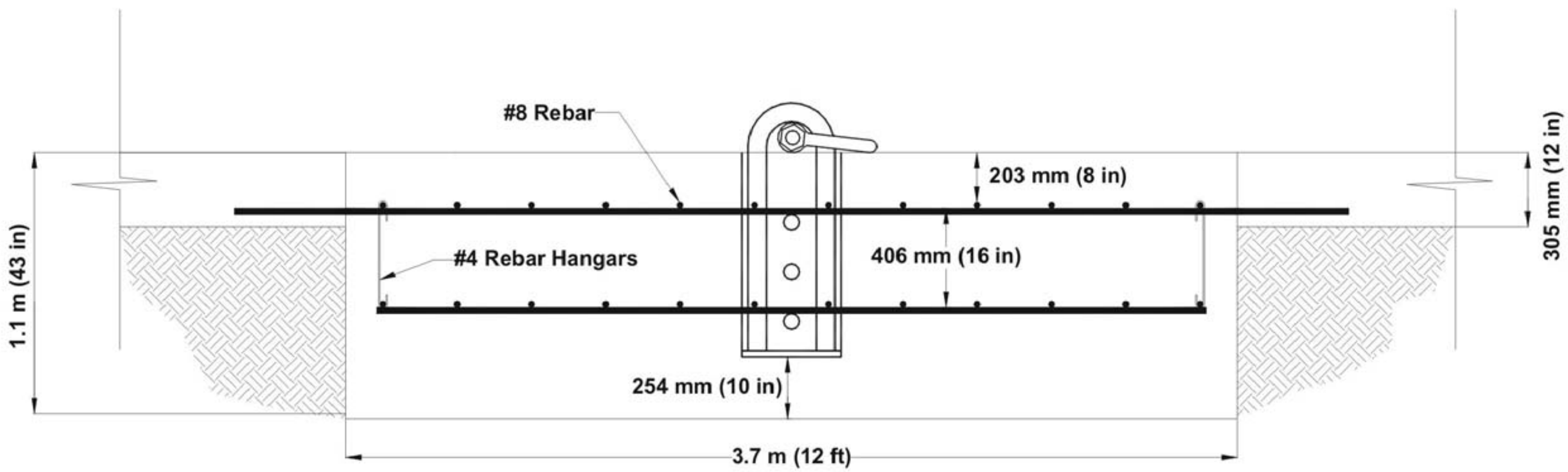

Figure A4. Anchor Block Construction – Profile View

CONSTRUCTION PHOTOS

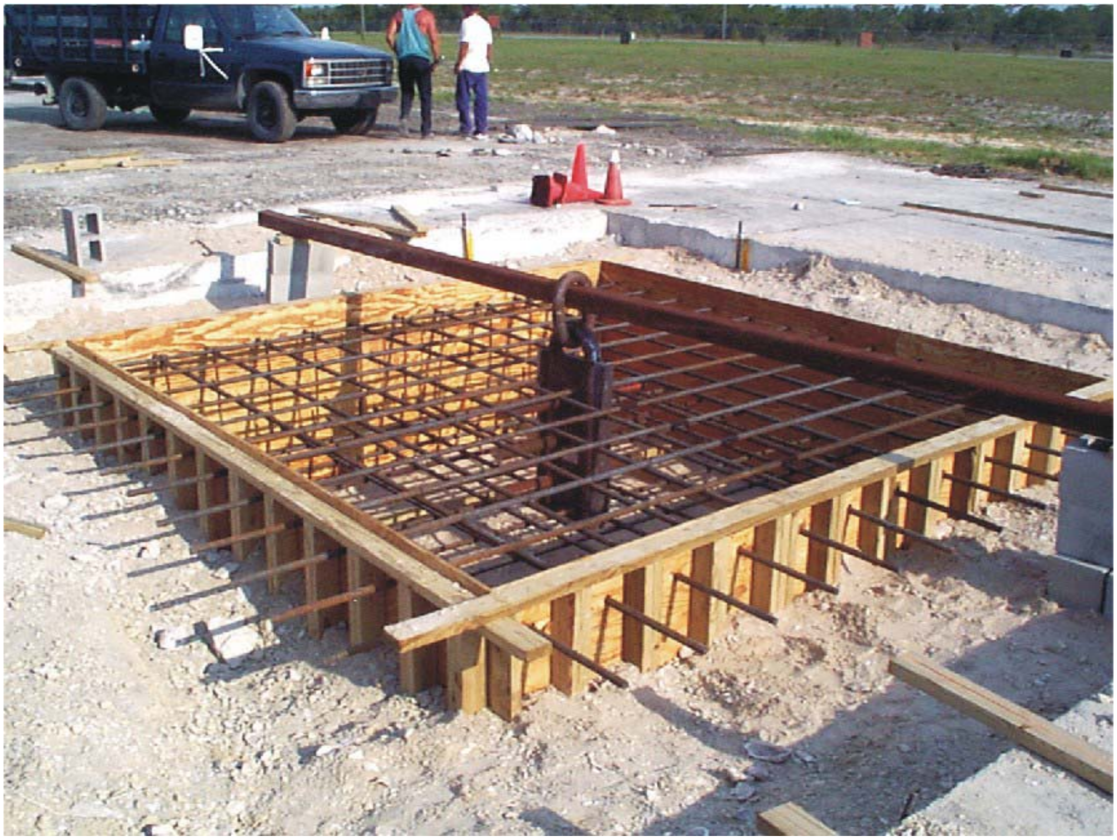

Figure A5. Trim Pad Anchor Construction

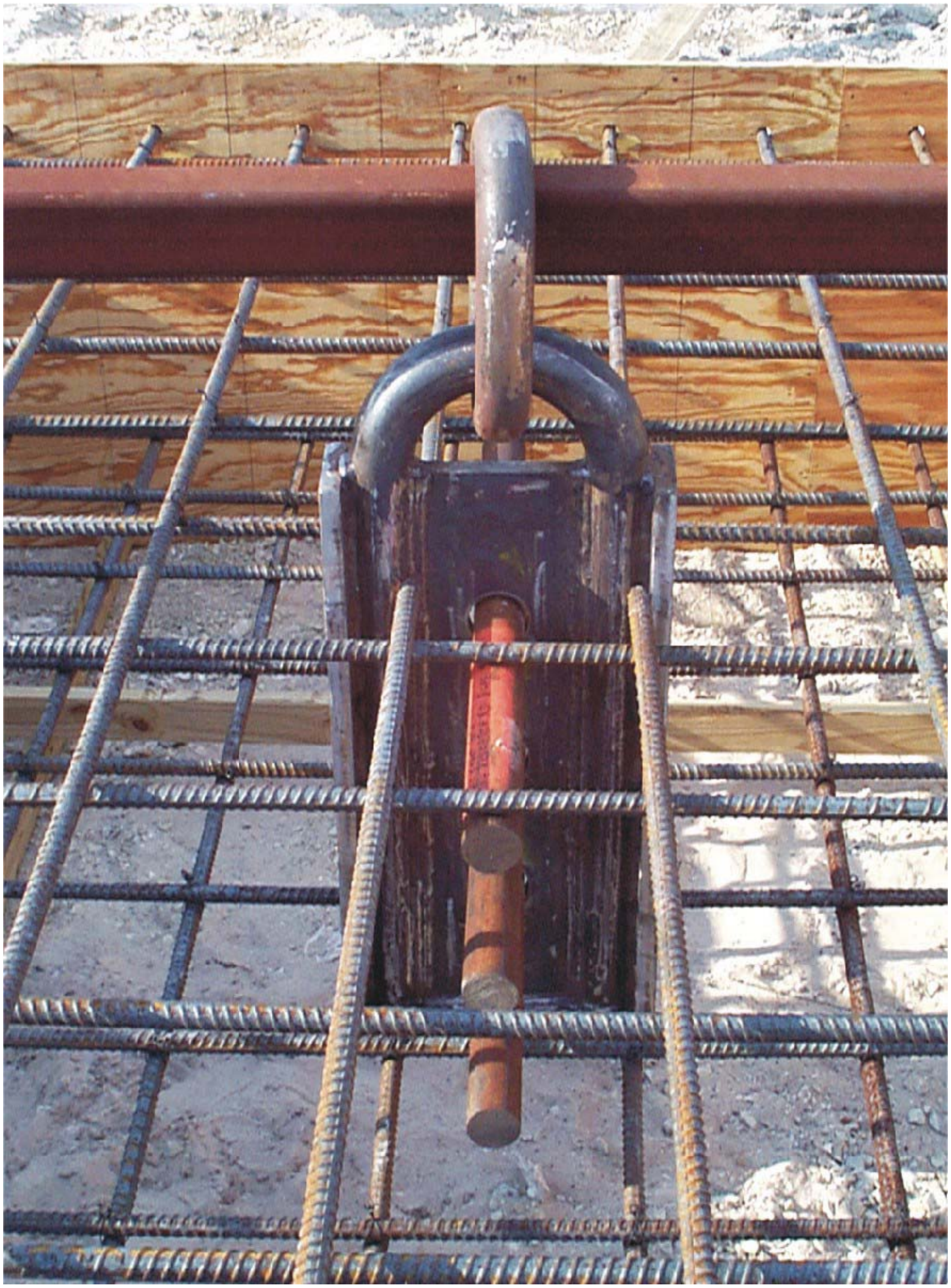

Figure A6. Steel Anchor in Place

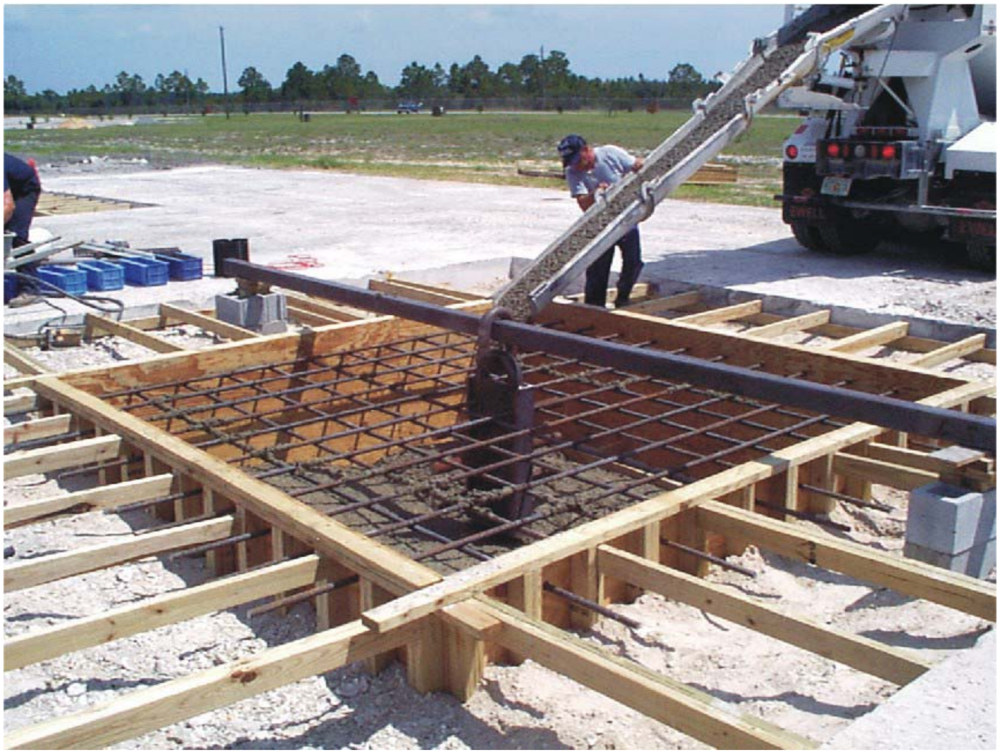

Figure A7. Placing Concrete

Figure A8. Cured Anchor Block

Figure A9. Preparing to Place Surrounding Concrete

Figure A10. Anchor Design Testing Configuration

Figure A11. Welded Link Fractured During Testing

Figure A12. Commercial Shackle Components

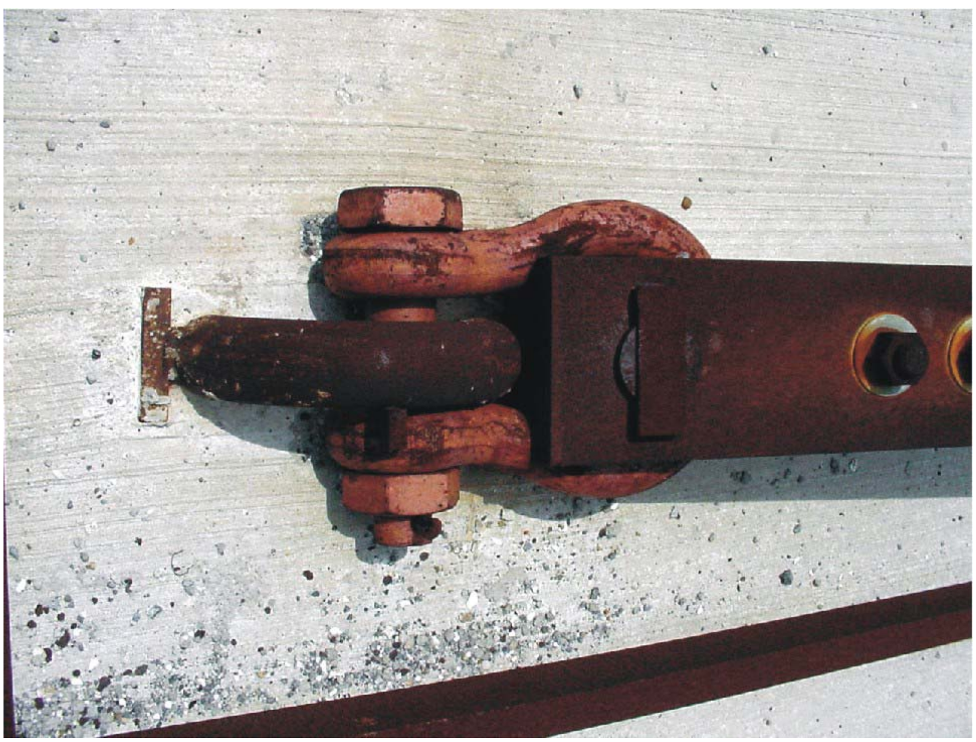

Figure A13. Commercial Shackle Replacing Fractured Welded Link

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